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FATHER HAGEN'S PAPERS ON DARK NEBULÆ

By Knut Lundmark

Father Hagen has recently published the following papers concerning dark debulæ:

(1) A map showing Obscure Nebulæ and their situation towards the Milky Way. *Monthly Notices, R. A. S.*, **81,** 449, 1921.

(2) Stufenschätzungen dunkler Nebel, *Astr. Nachr.*, **214,** 449, 1921.

(3) Dunkle Nebel und Sterneleeren, *Astr. Nachr.* Jubiläumsnummer, 1921.

(4) Die dunklen kosmischen Nebel, *Astr. Nachr.*, **213,** 351, 1921.

(5) The nebular envelope of our stellar system, *Scientia*, **31,** 185, 1922.

(6) An article in a number of Die Naturwissenschaften.

The first two papers and the fifth give the general results of a survey of dark nebulæ conducted by Father Hagen. In the second paper information is given concerning the methods used in making the observations, and in the third a comparison is given between the dark nebulæ in *Taurus* and the star counts for the same region published by the Greenwich observers. The fourth paper, in addition to some general conclusions, deals with the dark nebulæ identified as N. G. C. objects.

Concerning the observations the following facts may be of interest. The instrument used is a visual refractor of 16 inches (40.6 cm.) aperture and the focal length evidently is 611.3 cm.; thus the focal ratio is 1/15. The field has a diameter of 25′.4. For these observations the instrument is clamped and the driving clock used. The refractor is swept in declination and the density of the nebulosity in the field estimated on an arbitrary scale from 1 to 5.

After sweeping an arc of declination with a length of 10°, the instrument is changed 1° in right ascension and the sweeping done for another declination circle. Thus the survey is continuous in declination but not in right ascension as the observed strips are separated somewhat more than half a degree. The published charts of dark nebulæ as observed by Father Hagen show that these generally are more extended than the field of the refractor used. For this reason they must be difficult to observe, as the observer usually has to estimate the density of the cosmic clouds without taking advantage of the contrast between the "undarkened" sky and the dark nebulae. As to the possibility of observing dark nebulae by visual methods it is, of course, hard for an observer with my small experience to express any definite opinion, but it should perhaps be remembered that one of the keenest observers since Herschel, E. E. Barnard, has not found many of his 182 dark nebular objects visually but most of them by photography, although he was engaged in extensive visual observations before he began photographing the Milky Way. It is true that he was familiar with the nebulous region of ρ *Ophiuchi* at this time and that other regions had also attracted his attention before he commenced his photographic work. These regions, however, were situated in or close to the Milky Way structure. It was the dullness of the field and absence of stars that attracted the observer's attention. When he later photographed the objects suspected to be dark nebulæ some appeared as semi-vacant regions and it is very doubtful whether these are related to dark matter. Indeed, much is in favor of the opinion that these regions are sometimes real vacancies among the stars.

The difficulties of observing dark nebulæ visually are perhaps best illustrated by Barnard's statement that the small dark notch in the nebulosity south of ζ *Orionis,* whose outlines are so sharp and clear on photographs of this region, could not be made out with any definiteness by visual observations.

The most sensational result of Father Hagen's visual observations for obscure regions is that he considers practically the whole sky outside of the Milky Way to be covered with dark nebulæ. Barnard's and Hubble's extensive photographic studies of dark nebulæ have given as one main result that these are Milky Way objects related to the star clouds and, according to Hubble, also to the so-called secondary Galaxy (the local cluster). Hubble has not yet found any dark nebula at higher galactic latitude than 37°, and the one object at this distance from the Milky Way is quite an exception with regard to its location in the sky. Neither has he found any evidence for dark nebulæ at the galactic polar regions, although, independently of Father Hagen, he was investigating the possibility that such objects may exist in non-galactic regions.

On account of the importance of the problem of the cosmical distribution of dark matter, before the revolutionary conclusions which are a consequence of Father Hagen's results can be accepted, his observations ought to be repeated by another observer, in another climate, using a telescope with a larger focal ratio and a field of several degrees. The dark nebulæ known from previous photographic work should be used to test the visual method. Perhaps long-exposure photographs made with color screens, of some of the dark nebulæ in Barnard's catalogue would give a good means of testing what ability the human eye actually has for observations of this kind. Due attention should also be given to the question, under what conditions of random distribution of stars, false star caves or rifts appear and mislead the observer.

The effects of the zodiacal light and the so-called "earthlight" ought of course to be carefully investigated in observations of the kind Father Hagen describes. Concerning these sources of errors no mention seems to be made in his papers. There are also several physiological effects to be considered. In this connection it may be instructive to compare the existing drawings of the Milky Way. For example we find that Boediker's drawings, although very carefully executed, evidently give a very individualistic representation of the phenomenon as compared with the drawings of Easton and Pannekoek, which correspond fairly to what an "average" observer after some experience is able to make out of the Milky Way as seen by the unaided eye. It seems likely that Boediker's peculiar representation of the Milky Way structure could be partially explained by assuming the observer to have a color equation for objects near the limit of visibility.

In the discussion of his results Father Hagen tries to explain the absence of the spirals from the Milky Way. He considers them to be associated with the dark nebulæ, which surround the Milky Way system as a hollow shell. Attributing the same shape and dimensions to the hollow of the cosmical matter in which our system is imbedded as to the system itself, he concludes that the spirals existing in the Milky Way are six times as far away as the spirals at the pole. He accordingly concludes that the light coming to us from the Milky Way spirals is thirty-six times less than that from the spirals at the poles, and hence too faint to impress an image on the photographic plate. He seems to overlook the fact that the spirals are not points but have extension and thus the only effect on photographic observations will be that the spirals in or near the Milky Way will appear systematically smaller than the objects at the poles. He probably has in mind that the *total* amount of light from a nebula becomes smaller with increasing distances of the objects.

Holetschek, Kritzinger, and the writer have tried to estimate the total light impression we receive from a nebula by using the smallest possible optical means (field glasses, binoculars, finder telescopes, comet finders) and by comparing the objects with surrounding stars and with each other. Our results agree well and show that the brightest spirals have an integrated or total magnitude of 7^m-8^m except the Andromeda Nebula, which is very large and estimated by several observers at $5^m.0$. Spirals in the Milky Way, if we assume with Father Hagen that they send us 1/36 as much light, ought then to have a magnitude between 11^m and 12^m. In the 6-inch comet finder at Upsala ($f=1/6$) it was easy to recognize spirals with an integrated magnitude of 12^m. The same instrument, under observing conditions like those on the Pacific Coast, would show still fainter objects, and of course a larger telescope would show much fainter spirals. Thus we see that both photographic and visual observations should easily show the spirals supposedly close to or in the Milky Way.

The suggestion that the Milky Way system is rotating is interesting, but from the relative motion between the spirals and the Sun it is scarcely possible to decide if the group of stars near the Sun describes an orbit or is in relative rest with reference to the larger stellar system and rotates with it. If there is any indication in the data we now possess concerning the motion of our local system, it is that the rotation does not play any important part compared with the orbital motion.

Father Hagen suggests the hypothesis that the stars originate from the dark nebulæ, and as he assumes Russell's scheme of stellar evolution, it follows that the red giants ought to show a connection with dark nebulæ. As is well known the early spectral classes show a direct connection with the bright galactic nebulæ, and there is also some evidence of a relationship between these and a number of Barnard's dark nebulæ. A very small number of stars of later classes are also connected with nebulosity, and the Md star, R *Aquarii,* according to Merrill's and Lampland's discoveries is immersed in nebulosity. As this is the only known case of an M giant associated with a nebula, we want to see how the M giants are distributed in the sky. A plot of known M giants whose luminosities are obtained from trigonometric or spectroscopic parallaxes, shows that they are distributed rather uniformly all over the sky; in several cases they avoid the bright star clouds in the Milky Way as do the novæ[1], and occur where the star density is low, or where obscuring masses are assumed to exist; but a detailed correlation of the location of M giants with the structure of the Milky Way shows that this rule is not general and such a connection as seems to exist between novæ and nebular matter is only mildly suggested in the case of red giants.

As the M dwarfs are very rare it is fair to assume that most of the Ma, Mb, Mc stars in the Henry Draper Catalogue are giants. The following counts from this Catalogue showing the percentage of M stars to all the stars may be of interest.

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[1] *These Publications,* **33,** 219, 225, 1921.

Region	Area in Square Degrees	Number of Stars Per Square Degree	M Stars Per Square Degree	Percentage of M Stars
Cygnus star cloud	44	12.8	0.16	2.0
Auriga star cloud	105	5.7	0.13	2.5
Orion region	100	7.3	0.06	0.9
The Whole Sky	...	5.4	0.09	1.7

It is remarkable that the M stars occur in a smaller proportion in the Orion region where, as is well known, much bright and dark nebular matter exists.

For obtaining the galactic condensation of the M stars we make use of Pickering's counts in these Publications, volume **33,** page 144, 1921, and obtain the following numbers:

Region	Area in Square Degrees	Total Number of Stars	M Stars
Northern Galactic pole	400	783	13
Galactic equator	400	1913	21
Southern Galactic pole	400	1334	24

From this and the foregoing table we see that the M stars have no clear galactic concentration. The same is the case with M stars visible to the unaided eye.

In these counts the long period variable stars are not included. The parallaxes of a few of them have been measured by van Maanen with results which place them among the giants. Moreover, their motions show that they have a very high luminosity. By using the proper motions of Boss and Norlund, Gyllenberg found the parallactic drift for the long period variable stars. From his radial velocities Merrill has obtained 56 km/sec for the Sun's velocity with reference to the system of long period variable stars. Combining these results we get the mean absolute magnitude at maximum = — 2.8. As shown by Gyllenberg the apparent magnitude at maximum is more strongly correlated with the proper motion than is that at minimum. For this reason the maximum magnitude, m max, is used in the following computations.

If a constant value of the absolute magnitude is assumed.

the parallaxes for the M stars can be derived from the expression:

$$\log \pi = -0.2\ (\text{m max} + 7.8)$$

where π is the parallax.

For inspection of the galactic distribution of the long period variables the material in *Harvard Annals,* **56,** was plotted according to galactic coordinates and is shown in Figure 1. These stars seem to be somewhat more concentrated towards the galaxy than the ordinary M giants. Grouping the material according to galactic latitude we find:

Between Galactic Latitude	Number of Stars
—90° to —30°	125
—30 to 0	231
0 to +30	184
+30 to +90	96

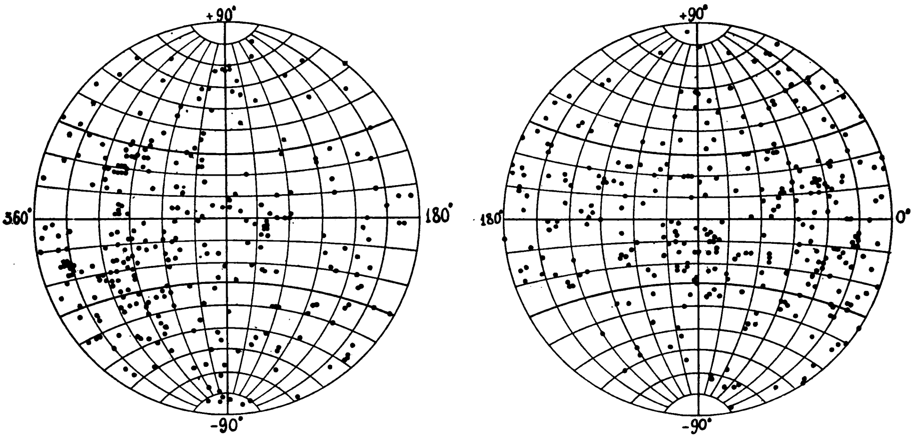

Fig. 1

Fig. 1. Distribution of long-period variable stars plotted in galactic coordinates.

The galactic concentration is 1.8. Although the stars in question are nearly twice as numerous in the galactic regions as in the non-galactic, it is remarkable that they seem to avoid the galactic clouds. Another connection with the Milky Way is shown in their distribution according to galactic longitude.

From Galactic Longitude	Number of Stars
0° —30°	75
30 —60	75
60 —90	43
90 —120	50
120 —150	36
150 —180	43
180 —210	31
210 —240	28
240 —270	43
270 —300	54
300 —330	98
330 —360	55

The concentration between 300° and 330° galactic longitude is very interesting as showing an analogy with the galactic distribution of globular clusters, novæ and other principal Milky Way objects[1].

The material at hand suggests a rather obscure connection between the nebular matter in the Milky Way and the giants of the classes Ma to Md. But even if we assume for a moment that this suggested relation is well established, Father Hagen's hypothesis is not supported. According to him the dark nebulæ are most numerous at the Milky Way poles. Therefore, if stars originate from dark nebular matter this would suggest that the M giants are the more numerous *outside* the Milky Way. This is not the case, and it seems necessary to await further observations before Father Hagen's idea of a "Nebular Way" with its densest parts at the galactic poles can be accepted.

Furthermore, if the cosmic clouds are densest at the Galactic poles and also located nearer to us than the nebular matter in the Milky Way, we should expect their gravitational pull to cause the majority of stellar motions to be *at right angles* to the galactic plane. As is well known, however, the motions of the stars show a general tendency to group themselves in directions *parallel* to the plane of the Milky Way.

Assuming enormous masses of nebulosity to exist at the

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[1] As the higher frequency of long period variables in the direction of the center of our stellar system shows that the distant variables extend out to this center we get an estimate of the distance from us to the central region of our stellar system. From the formula above and photometric data in *Harvard Annals* 56 we find $\pi = 0''.0003$, which indicates that the center of our stellar system is at least 10000 light years distant.

Milky Way poles, and situated at moderate distances, we probably should get phenomena of extinction and scattering among the stars. Our material at present may not be conclusive for a decision of this question, but as far as the evidence goes it is that in the Milky Way we have local scattering and extinction and not at the polar regions.

I am indebted to Dr. Shapley for communicating unpublished data from the Henry Draper Catalogue. I am also indebted to Professor Barnard and Dr. Hubble for valuable information concerning their observations of nebulæ.

March 15, 1922.